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S. C. Lu

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SEISMIC EVALUATION PROCEDURE FOR GLOVE BOXES AT U.S. DEPARTMENT OF ENERGY FACILITIES

Stephen C. Lu
Lawrence Livermore National Laboratory
P.O. Box 808, Livermore, CA 94550 USA
Tel: (925)422-0318 Fax: (925)422-5497
e-mail: Lu1@LLnL.gov

ABSTRACT

At U.S. Department of Energy (DOE) facilities, safety analyses and facility-specific actions require the evaluation of mechanical and electrical equipment subjected to seismic hazards. A seismic evaluation procedure has been developed by the DOE to provide comprehensive guidance for consistent seismic evaluations of equipment and distribution systems in DOE facilities using experience data from past seismic events and shake table tests. The DOE Seismic Evaluation Procedure (SEP) is adapted from the Seismic Qualification Utility Group (SQUG) Generic Implementation Procedure (GIP) used by the nuclear power industry. The DOE SEP builds on the procedures and screening criteria in the SQUG GIP by incorporating DOE-specific requirements and guidance and broadening the application of the experience-based methodology to equipment classes which are either unique to DOE facilities or not contained in the SQUG GIP. These equipment classes include piping systems, HEPA filters, glove boxes, underground tanks, canisters and gas cylinders, HVAC ducts, storage racks, etc. This paper addresses the seismic evaluation procedures developed uniquely for glove boxes.

INTRODUCTION

The safety policy of the United States Department of Energy (DOE), specified by SEN-35-91, Nuclear Safety Policy (DOE, 1991), and DOE 5480.1B, Environmental, Safety, and Health Program for DOE Operations (DOE, 1986), requires DOE facilities be designed, constructed, and operated so that workers, the general public, and the environment are protected from the impacts of natural phenomena hazards (NPH) such as earthquakes, extreme winds, and flooding.

Mechanical and electrical equipment may be seismically qualified by analyses, testing, or past earthquake experience data. The Seismic Qualification Utility Group (SQUG) developed a Generic Implementation Procedure (GIP) (SQUG, 1992) which has been applied with great success to the qualification of mechanical and electrical equipment at nuclear power plants by using past earthquake experience and test data. In recent years, this procedure has been adapted and modified for use in seismic evaluation of equipment at DOE facilities. The DOE Seismic Evaluation Procedure (SEP) (DOE, 1997) builds on the procedures and screening criteria in the SQUG GIP by incorporating DOE-specific requirements and guidance and broadening the application of the experience-based methodology to equipment which are either unique to DOE facilities or not contained in the SQUG GIP. These equipment classes include piping systems, HEPA filters, glove boxes, underground tanks, canisters and gas cylinders, HVAC ducts, storage racks, etc. This paper addresses the seismic evaluation procedures developed uniquely for glove boxes.

OVERVIEW OF SQUG GENERIC IMPLEMENTATION PROCEDURE

The method of seismic qualification of mechanical and electrical equipment for DOE facilities by earthquake experience data is derived from the Generic implementation Procedure (GIP) used for qualifying mechanical and electrical equipment associated with nuclear power plants under the sponsorship of the Seismic Qualification Utility Group (SQUG, 1992).

The SQUG GIP consists of four sets of criteria:

- The experience-based capacity spectrum must bound the plant seismic demand spectrum. In accordance with the SQUG-GIP, the seismic capacity of a component in one of the SQUG classes is represented by the experience-based

- The experience-based capacity spectrum must bound the plant seismic demand spectrum. In accordance with the SQUG-GIP, the seismic capacity of a component in one of the SQUG classes is represented by the experience-based Reference Spectrum (i.e., 1.5 x Bounding Spectrum) depicted by Figure 4-2 of (SQUG, 1992) or a Generic Ruggedness spectrum (GERS) based on generic seismic test data. The demand of that component is represented by the in-structure response spectrum. In the SQUG GIP, the "40-foot rule" permits the use of the Bounding Spectrum to define the capacity for equipment with fundamental frequencies greater than about 8 Hertz and mounted within 40 feet above effective grade. The Bounding Spectrum has a generic de-amplification of 1.5 as compared to the Reference Spectrum and is a simplified way for reducing the experience-based capacity to account for in-structure amplification.
- In order to apply the SQUG GIP, the equipment item must be reviewed against certain inclusion rules and caveats. Caveats are defined as the set of inclusion and exclusion rules that represent specific characteristics and features particularly important for seismic adequacy of a particular class of equipment.
- The component anchorage must be evaluated. Anchorage as-installed conditions and capacity must in general be verified for seismic qualification of mechanical and electrical equipment. Anchorage verification is especially important if experience data are used because the experience data cannot be applied unless appropriate anchorage is provided. Anchorage verification can usually be achieved by plant walkdown followed by simple calculations, if necessary. Guidelines for evaluating the seismic capacity of anchorage are addressed in detail in (SQUG, 1992). The strength of anchor bolts usually should be subjected to a verification process to address items such as inspection for cracks in concrete, tightness checks to ensure proper bolt installation, review of bolt minimum embedment length, bolt edge distance and spacing, and anchorage load path.
- Any potentially significant seismic systems interaction concerns that may adversely affect the component function must be addressed. Seismic systems interaction often results in potential hazards during earthquakes. Seismic systems interaction is the physical interaction (bumping, falling) of items close to one another. Vital components with fragile appurtenances (such as instrumentation tubing, air lines, and glass site tubes) are most prone to damage by interaction. The types of seismic systems interactions that should be investigated include (1) structural failure and falling, (2) proximity and impact, and (3) differential displacement. A in-plant walkdown usually is the most cost-effective means for evaluating seismic interaction effects.

These SQUG GIP criteria are in the form of screening evaluation guidelines. Items not passing the screen (called "outliers") are not necessarily inadequate, but other seismic engineering methods must be used to further evaluate the outliers. The screening evaluation adopted in the SQUG GIP is generally a conservative and rapid appraisal process that is used during a facility walkdown to verify acceptability or identify outliers by review of key physical attributes. Items passing the screen are verified as acceptable and may be documented as such. Items not passing the screen are not verified and are formally designated as outliers, which must be subject to more detailed review or upgrade before being accepted. Prior to a screening evaluation, a system review is conducted to assess the minimal and prioritized scope for the evaluation.

An important element of the SQUG GIP is its application by the use of a specially trained and experienced seismic review team (SRT) of which the team members must exercise considerable judgment while performing the in-plant screening evaluation. Strict qualification requirements have been established for SRT members. One of the requirements is that they have to pass a 40-hour training course in the use of the implementation guidelines and procedures. In recent years, the SQUG procedure has been adapted and modified to be used for equipment qualification at DOE sites and a series of training courses have been offered by the DOE (DOE, 1995).

The experience-based SQUG method addresses most plant components, which include 20 classes of mechanical and electrical equipment, cable trays and conduit systems, relays, anchorage, tanks and heat exchangers. The database includes the response of systems and components in about 100 commercial and industrial facilities that were in the strong motion regions of 20 past earthquakes. The earthquakes have Richter magnitudes in the range of 5.2 to 8.1, have ground accelerations from 0.1g to 0.85g, and have about 3 to 50 seconds in duration.

SEISMIC EVALUATION CRITERIA FOR DOE FACILITIES

The seismic design and evaluation requirements at DOE sites and facilities are established by DOE Order 5480.28, Natural Phenomena Hazards Mitigation (DOE, 1993a). DOE Order 5480.28 establishes a graded approach in which natural phenomena hazards requirements are provided for various Performance Categories each with a target probabilistic performance goal. The motivation for the graded approach is that it enables design or evaluation of DOE structures, systems, and components to be performed in a manner consistent with their importance to safety, importance to mission, and cost. Five Performance Categories (PC) have been established, which range from PC-0 to PC-4. Performance Categories range from those for conventional buildings to those for facilities with hazardous materials or operations. Most DOE nuclear facilities are assigned to PC-3 or lower. The use of PC-4 is usually reserved for those facilities whose accident dose potential is similar to that of commercial nuclear reactors.

DOE-STD-1020-94 (DOE, 1994) provides criteria as the means of implementing DOE 5480.28 and executing the DOE NPH policy in a consistent manner throughout the DOE sites. Current seismic design and evaluation steps for new and existing nuclear facilities as specified in DOE-STD-1020-94 are summarized as follows:

- Determine Performance Categories of structures, systems, and components based on DOE-STD-1021 (DOE, 1993b).
- Determine the seismic loading.
- Determine the response of SSCs (Demand).
- Determine the Capacity of SSCs.
- Compare Demand and Capacity.
- Check for detailing of structures and/or anchorage and seismic interaction effects for equipment.

Structures, systems or components can be seismically qualified by analysis, testing, or using past earthquake (real or artificial) data experienced by identical or similar SSCs. In any case, a seismic walkdown is very useful in terms of identifying the as-built conditions, simple fixes, as well as adequate structural detailing such as sufficient anchorage and being free of undesirable seismic interaction.

For mechanical and electrical equipment, various methods including analysis, testing, or using earthquake experience data can be used to qualify the seismic capacity of the requirement. The method of using experience data, if applicable, has the merit of being the simplest one to use.

GENERAL APPROACH FOR DOE SEISMIC EVALUATION PROCEDURE

The DOE Seismic Evaluation Procedure expands the SQUG GIP by incorporating DOE-specific requirements and guidance and by broadening the application of the experience-based methodology to equipment classes not contained in the SQUG GIP.

The DOE Seismic Evaluation Procedure has three major adaptations for non-reactor applications:

- In the SQUG GIP, the "40-foot rule" permits the use of the Bounding Spectrum to define the capacity for equipment with fundamental frequencies greater than about 8 Hertz and mounted within 40 feet above effective grade. The Bounding Spectrum has a generic de-amplification of 1.5 as compared to the Reference Spectrum and is a simplified way for reducing the experience-based capacity to account for in-structure amplification. Since the "40-foot rule" was developed for nuclear power plants with massive and stiff shear wall structures that are not the typical structural types at DOE facilities, the DOE Seismic Evaluation Procedure does not have the "40-foot rule" or the Bounding Spectrum. Instead, the DOE approach uses the Reference Spectrum to define equipment capacity and to compare with in-structure response spectra developed at equipment locations.
- The DOE Seismic Evaluation Procedure has equipment classes that are not in the SQUG GIP, such as piping systems and unreinforced masonry walls.
- The relay review for DOE facilities focuses primarily on identifying low ruggedness relays and comparing seismic capacity to demand. The detailed procedure which is required for relay functionality reviews in nuclear power plants is not included in the DOE Seismic Evaluation Procedure.

Since DOE facilities are not structurally equivalent to nuclear power plants, which are typically stiff, shear wall structures, the approach in the SQUG GIP for comparing seismic capacity with seismic demand has been modified for DOE usage. In contrast to the SQUG deterministic criteria, DOE facilities are required to demonstrate the ability to achieve probabilistic performance goals. In order to achieve this requirement, experience data factors are used to scale in-structure response spectra that are derived from the Design Basis Earthquake (DBE) for a facility. The scaled in-structure spectra, or the Seismic Demand Spectra (SDS), are compared with experience-based capacity spectra. The scale factors are similar to safety factor or the inherent conservatism in the acceptance criteria or structural design codes.

Performance Category	Scale Factor (SF)
1	N. A.
2	0.67
3	1.00
4	1.25

In the design of new equipment, rules are specified such that a known margin exists between the design value and the ultimate failure level. This margin has been considered in developing the seismic design and evaluation criteria for DOE facilities as provided by DOE-STD-1020. A similar margin is required for the use of capacity obtained from experience data. The margin between the design and ultimate failure values are contained in the experience data factor, F_{ED}.

Capacity Presentation	Experience Data Factor
Reference Spectrum	1.0 SF
GERS	1.4 SF
Relay GERS	1.8 SF
Qualification Test	1.4 SF

To evaluate the seismic demand at the equipment attachment point, an in-structure response spectrum (IRS) is scaled by F_{ED} to determine the Seismic Demand Spectrum (SDS) according to the following formula:

$$SDS = F_{ED} \times IRS.$$

SEISMIC EVALUATION PROCEDURES ADOPTED DIRECTLY FROM THE SQUG GIP

Equipment that can be evaluated by seismic evaluation procedures adopted directly from the SQUGGIP can be divided into two categories: equipment classes that can be evaluated by using caveats for the Reference Spectrum and/or GERS and equipment classes that can be evaluated by using screening procedures.

Equipment classes that can be evaluated by using caveats for the Reference Spectrum and/or GERS include the following electrical and mechanical equipment classes:

Electrical Equipment:	Batteries on Racks Motor Control centers Low Voltage Switchgears Medium Voltage Switchgears Distribution Panels Transformers Battery Chargers and Inverters Instrumentation and Control Panels Instruments on Racks Temperature Sensors
Mechanical Equipment:	Fluid or Air Operated Valves Motor or Solenoid Operated Valves Horizontal Pumps Vertical Pumps Chillers Air Compressors Motor Generators Engine Generators Air Handlers Fans

Equipment classes that can be evaluated by using screening procedures include above ground vertical and horizontal tanks and heat exchangers and cable and conduit raceway systems. The screening procedures for evaluating the seismic adequacy of the different equipment classes cover those features which experience has shown can be vulnerable to seismic loading. These procedures are a step-by-step process through which the important equipment parameters and dimensions are determined, seismic performance concerns are evaluated, the equipment capacity is determined, and the equipment capacity is compared tot he seismic demand.

SEISMIC EVALUATION PROCEDURES DEVELOPED UNIQUELY FOR THE DOE

The DOE Seismic Evaluation Procedure expands the SQUG GIP by incorporating DOE-specific requirements and guidance and by broadening the application of the experience-based methodology to equipment classes not contained in the SQUG GIP. The seismic evaluation procedures developed uniquely for the DOE apply to the following classes of equipment or systems:

Piping
Underground Piping
HEPA Filters
Glove Boxes
Miscellaneous Machinery
Underground Tanks
Canisters and Gas Cylinders
HVAC Ducts
Unreinforced Masonry Walls
Raised Floors
Storage Racks

Equipment is to be evaluated by using screening procedures or general guidelines.

The screening procedures for evaluating the seismic adequacy of the different equipment classes cover those features which experience has shown can be vulnerable to seismic loading. These procedures are a step-by-step process through which the important equipment parameters and dimensions are determined, seismic performance concerns are evaluated, the equipment capacity is determined, and the equipment capacity is compared tot he seismic demand.

The general guidelines for evaluating the seismic adequacy of the equipment classes cover those features which experience has shown can be vulnerable to seismic loading. These practical guidelines and reference to documents can be used to implement an equipment strengthening and upgrading program. The relatively simple seismic upgrades are designed to provide cost-effective methods of enhancing the seismic safety of the equipment classes.

GENERAL GUIDELINES FOR SEISMIC EVALUATION OF GLOVE BOXES

Glove boxes serve as primary confinement for radioactive or hazardous materials. As such, the pressure inside a glove box is less than the room pressure external to the glove box. Therefore, maintaining the pressure boundary is important when evaluating the seismic adequacy of glove boxes.

This section describes general guidelines that can be used for evaluating and upgrading the seismic adequacy of glove boxes whch are based on analytical and walkdown experience at various DOE sites. Guidelines in this section cover those features of glove boxes which experience has shown can be vulnerable to seismic loadings.

In evaluating glove boxes, the following five areas should be evaluated:

1. Seismic Interaction Effects

As with other equipment, glove boxes can be vulnerable to interaction effects. Seismic interaction effects should include flexibility of attached tubing and conduit and interaction with components or equipment located inside the glove boxes (heat sources, furnace, vacuum chamber, or flammable materials).

The evaluation should examine interactions which are both internal and external to the box. The evaluation is to assure that (1) external components such as power supplies and furnaces, which directly support glove boxes activities, are restrained to prevent impact with windows and support frames; (2) internally objects such as conveying systems and machining tools are anchored to the box so that they cannot slide and tear gloves and break windows; and (3) attached tubing and conduit have enough flexibility to accommodate the seismic motion of the glove box.

2. Load Path

Load path refers to the manner in which inertial loads acting on the glove boxes and associated equipment are transferred through the glove box structure to the supporting framework, to the anchorage, and into the supporting structure. The evaluation is to assure that (1) during seismic evaluations, the load path, including connections, is carefully reviewed for adequate strength, stiffness, and ductility; and (2) attachments, such as filtration devices and furnace wells, are adequately anchored to the box; and (3) the box is adequately attached to the supporting framework.

3. Supporting Framework

The supporting framework of glove boxes is one aspect of the evaluation in which structural calculations may be necessary to determine seismic adequacy. The supporting framework should be reviewed for missing or altered (cutouts, notches or holes) members. Frames which rely on moment connections to provide lateral support and are constructed of unistrut or single angle legs have been found to be especially vulnerable. Braced frames are generally less vulnerable.

4. Leak Tightness

Glove boxes serve as primary confinement for radioactive or hazardous materials. As such, leak tightness is an important feature of the glove boxes system. The evaluation should assure that interaction effects, load path, and supporting framework, in particular the relative displacements which connections boxes and attachments, will not jeopardize the integrity of the pressure boundary associated with a glove box.

5. Anchorage

Anchorage installation for all glove boxes should be inspected in accordance with applicable guidelines specified in Section 6.2 (Anchorage Installation Inspection) of DOE (1997). An area of concern which should be reviewed carefully is the gap between the bottom of the base plate and the floor. In many cases an individual glove box is part of a system or train of glove boxes in which one box is connected to another box. To maintain proper vertical alignment of the boses, shims are typically used beneath the base plate. These shims can introduce bending to the anchor bolts which can significantly reduce the capacity of the bolts.

According to Section 6.2.3 of DOE (1997), the size of the gap between the base of the equipment and the surface of the concrete should be less than about 1/4 inch in the vicinity of the anchors. This limitation is necessary to prevent excessive flexural stresses in the anchor bolt or stud and excessive bending moments on the concrete anchorage when shear loads are applied. Expansion anchors may have low resistence to imposed bolt bending moment which might result from gaps between base and floor. Anchorage with gaps larger than about 1/4 inch should be classified as outliers and evaluated in more detail. Guidance on resolving anchorage outliers is provided in EPRI (1994).

The pullout capacity allowable (P_{all}), based on Chapter 6 of DOE (1997), is the product of the nominal pullout capacity and the applicable capacity reduction factors:

$$P_{all} = P_{nom}\, RT_p\, RL_p\, RS_p\, RE_p\, RF_p\, RC_p\, RR_p\, RI_p$$

where: P_{nom} = Nominal tensile allowable
RT_p = Reduction factor for expansion anchors
RL_p = Reduction factor for short embedment
RS_p = Reduction factor for closely spaced anchors
RE_p = Reduction factor for near edge anchors
RF_p = Reduction factor for low strength concrete
RC_p = Reduction factor for cracked concrete
RR_p = Reduction factor for expansion anchors with essential relays
RI_p = Reduction factor for reduced inspection procedure

Determination of the nominal pullout capacity and the applicable capacity reduction factors for various types of anchorage, i.e., expansion anchors, cast-in-place bolts and headed studs, cast-in-place J-bolts, grouted-in-place bolts, lead cinch anchors, etc., is provided in Section 6.3 of DOE (1997). A similar procedure is provided for determination of the shear capacity allowable (V_{all}).

Seismic demand for anchorage is determined by the following steps:

The first step in determining the seismic demand loads on the anchorage is to compute the input seismic accelerations from an appropriate in-structure response spectrum, at the damping and natural frequency of the equipment, for the location in the facility where the equipment is mounted. The in-structure response spectrum is computed from the Design

The third step in determining the seismic demand loads on the anchorage is to compute the seismic inertial anchor loads foe each of the three direction of motion. This done by applying the seismic inertial equipment loads determined in the previous step to the center of gravity of the item of equipment and calculating the free-body loads on the anchors.

The fourth step in determining the seismic demand loads on the anchorage is to compute the combined seismic anchor loads of the seismic loads on each anchor from the three directions of earthquake motion. The combined loads can be computed with a combination technique such as the Square Root Sum of the Squares (SRSS) or the 100-40-40 Rule.

The fifth step in determining the seismic demand loads on the anchorage is to compute the total loads on the anchorage by combining the combined seismic anchor loads from the previous step to the equipment deadweight loads and any other significant loads which would be applied to the equipment, e.g., pipe reaction loads on the equipment.

CONCLUSION

The SQUG experience based DOE Seismic Evaluation Procedure has been used at many DOE facilities, namely, the Savannah River Site (WSRC, 1992), the High Flux Isotope Reactors at Oak Ridge National Laboratory, the Princeton Plasma Physics Laboratory, the Idaho Chemical Process Plant, and Lawrence Livermore National Laboratory (Lu and Chang, 1996). Applications of the seismic evaluation procedure at these DOE sites have proven the viability of using the experience-based methodology. Many of the results of these evaluations have withstood strict scrutiny during technical audits, peer reviews, quality control audits, and other independent reviews.

According to results of applying this methodology at various DOE sites, seismic qualification using experience data is often a technical necessity and is the most economically attractive of the options to qualify existing equipment. Representative costs for seismic qualification using the experience based methodology demonstrate costs are 70% lower than the costs for qualification using conventional methods such as seismic testing or detailed engineering analyses.

The basis for much of the DOE Seismic Evaluation Procedure is the SQUG Generic Implementation Procedure developed for nuclear power plants and endorsed by the NRC, with heavy multi-year involvement by an independent review body, the Senior Seismic Review and Advisory Panel. However, the scope of the SQUG guidance does not cover all of the safety relevant equipment in DOE facilities, so DOE has developed several extensions to evaluate additional equipment. One of such extensions is the development of general guidelines of seismic evaluation for glove boxes. It must be recognized that these extensions have not undergone the same degree of review and consensus building as the SQUG procedures for nuclear power plants. It is necessary to note that the pedigree of the DOE extensions at the current stage is not similar to that of the SQUG procedures. It is hoped, however, that the level of rigor of the DOE extensions will match that of the SQUG procedures after more experience has been gained in applying the guidelines and procedures developed uniquely for the DOE Seismic Evaluation Procedure.

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